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Gregg, Jay Sterling

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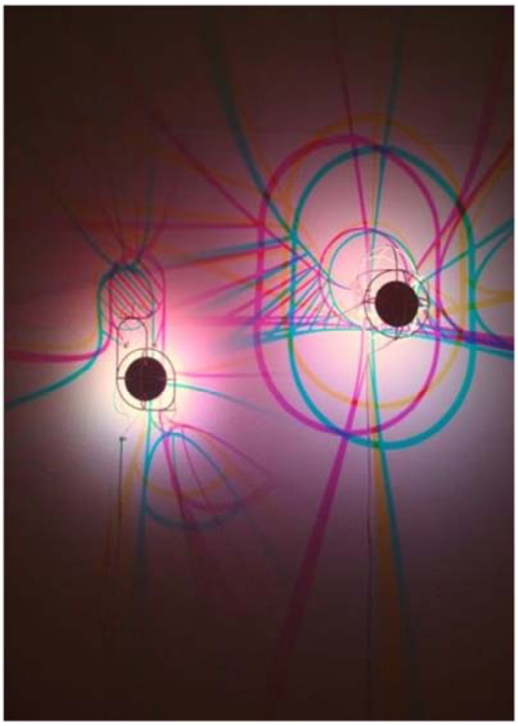
Potential Game Changers Towards A Zero Carbon EU Energy System by 2050

Jay Sterling Gregg

Technical University of Denmark

EERA e3s



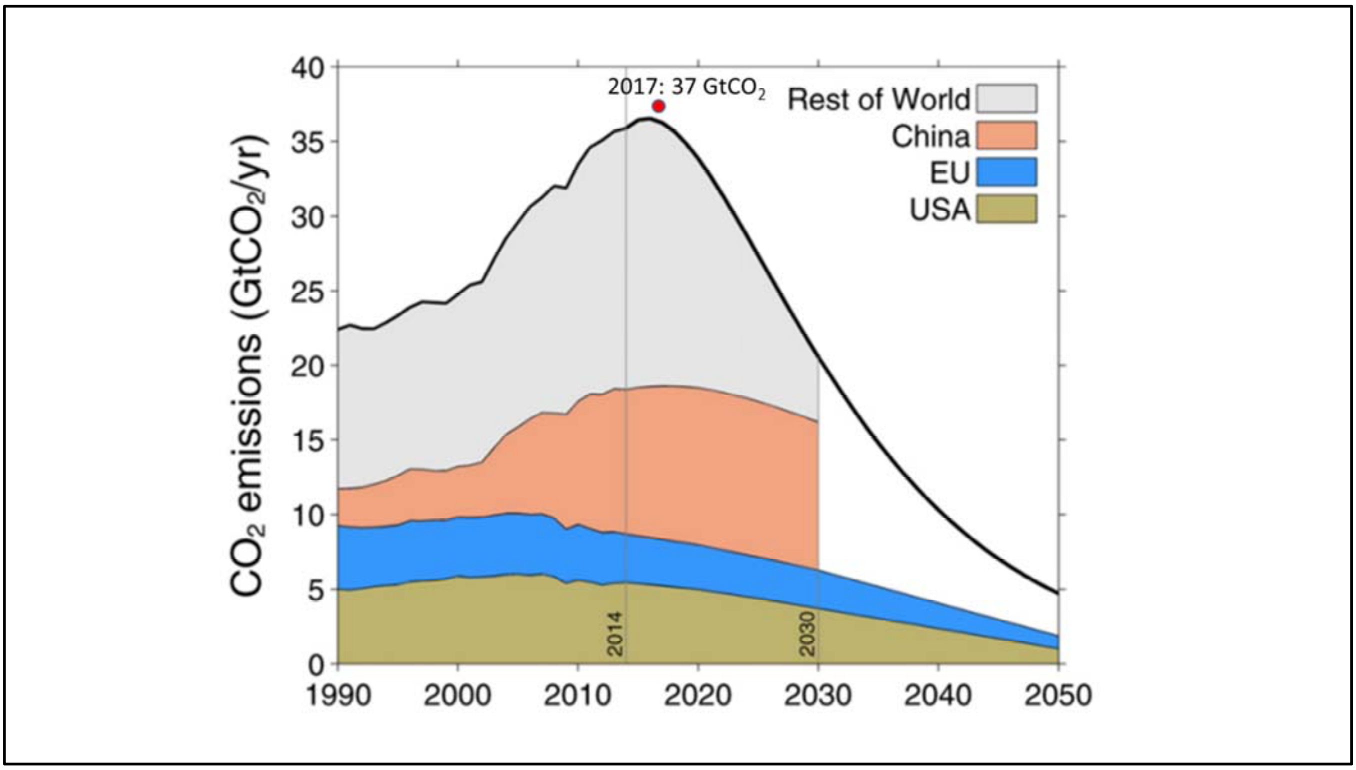
When we ask which energy technologies will be important in the future, it can sometimes feel like a horserace. We want to bet on the right horse to bring us to a sustainable future. Which energy source has the most potential? Which have the greatest uncertainties?

Methodology:

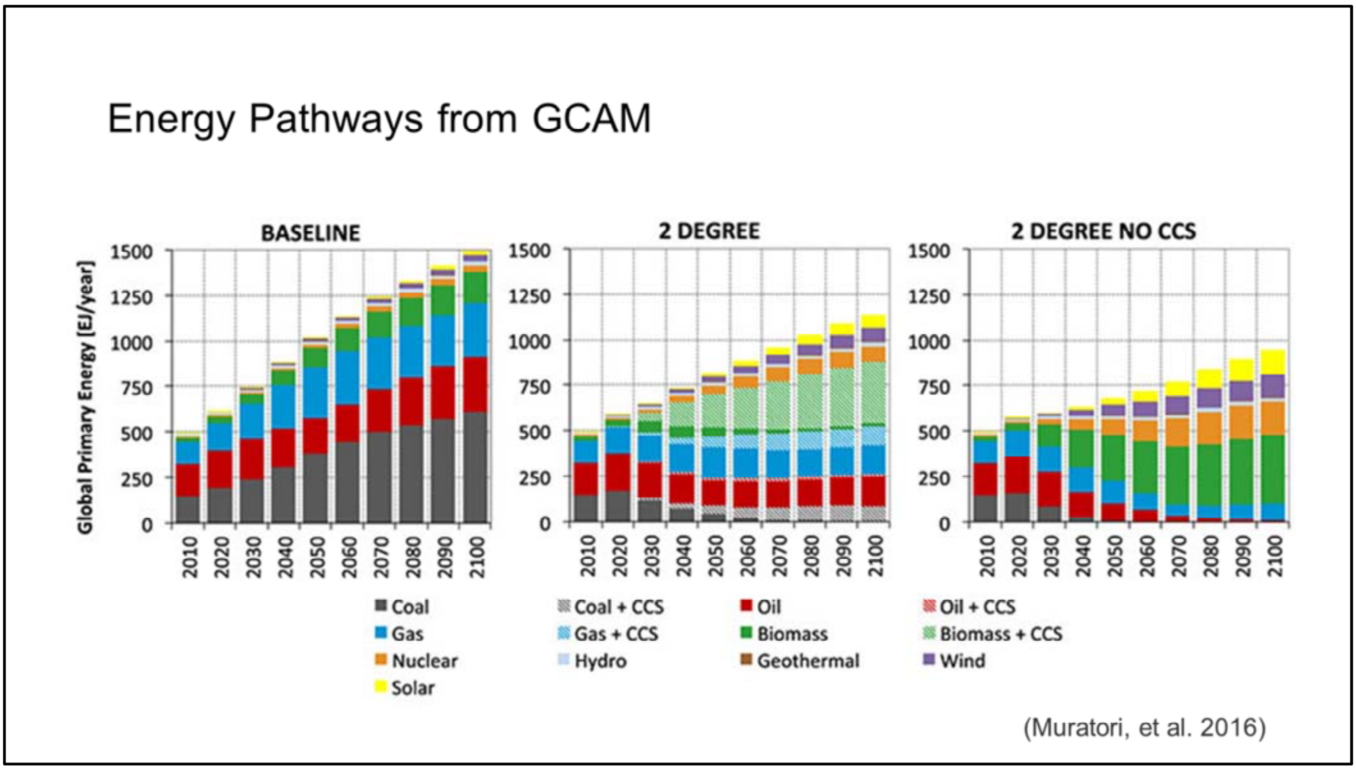
Integrated Assessment Modeling

This then leads to integrated assessment models, or E3 (Energy, Environment, and Economy) models.

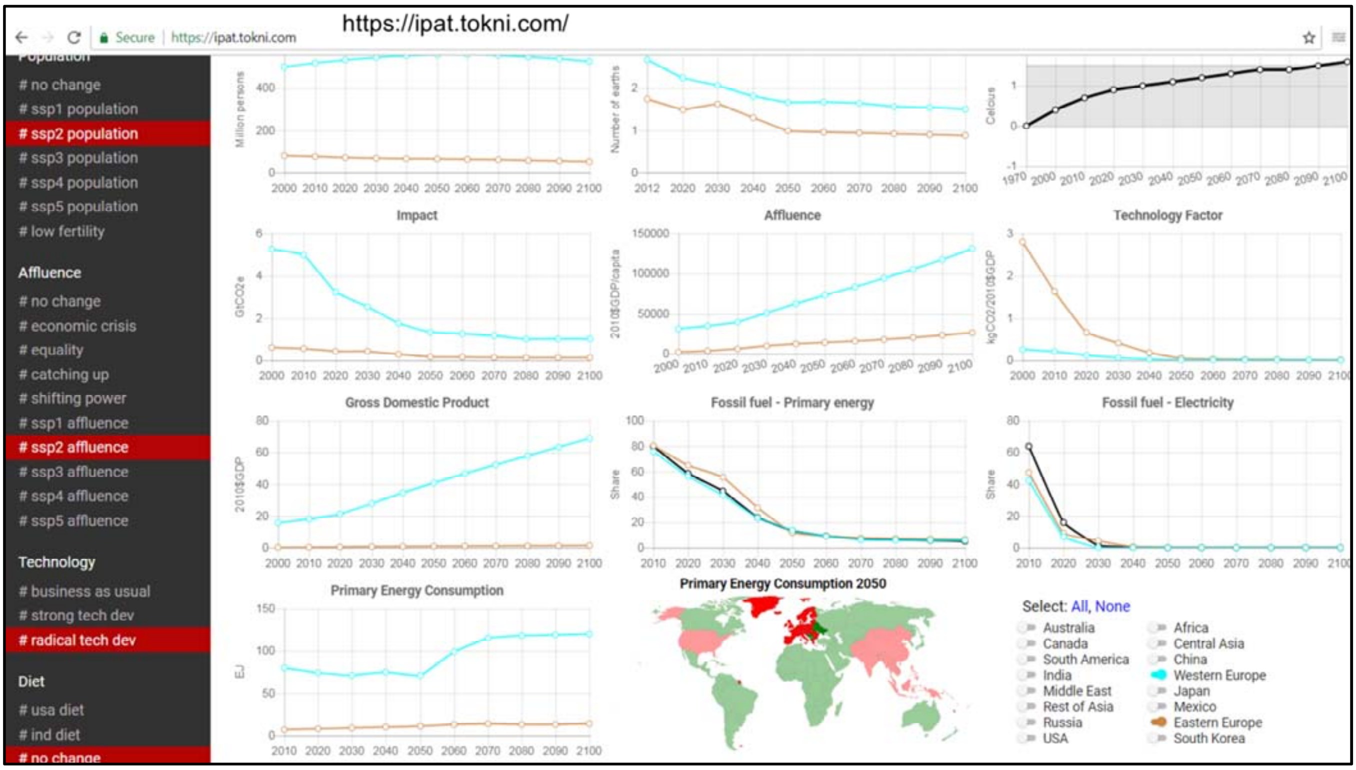
These models are quite complicated to describe in short presentation, but I would like to give a conceptual picture of what is going on. An integrated assessment takes exogenous projections of population, labor productivity, and therefore GDP, and uses that to calculate demand for energy services in transport, industry, buildings, as well as timber and food. On the other side, the model has data on energy resources and potentials (including price projections) for the fossil resources: coal, oil and gas; nuclear; and the renewables: solar, wind, geothermal, hydro, biomass. The model then has land availability by type, forest productivity, and agricultural production. These are then balanced by supply and demand, assuming free trade, and subject to policy constraints such as climate targets or taxes on emissions. The model then finds the optimal least cost solution.



Meeting a 2-degree target (or the even more ambitious 1.5-degree target) will not be easy. Given the current INDCs, there isn't much carbon budget left for the rest of the world.



Here are some examples from the Global Change Assessment Model, that is constrained to meet the 2.6 W/m2 radiative forcing limit that has a more likely than not change of keeping temperature increases under 2 degrees C. One scenario allows CCS, the other does not. The model depends heavily on bioenergy, which is currently our largest source of renewable energy, at around 55 EJ. Expanding this to 400 EJ by the end of the century is quite ambitious (I'll talk more later about bioenergy). I am not sure this is a future I want to live in.



At DTU, we have made a user friendly, simplified version of IAM results, based on I=PAT, that you can play with. You'll find that creating a sustainable future requires disruptive, revolutionary changes.

Planning for the Future

- Is it possible for a model to predict the future of a human system?
- Is it possible to validate the model by running from a past date to the present?
- What will happen in the future?
- What will we learn in the future?
- What will we value?

IAMs: population, economy, elasticities, future prices, tech parameters are all exogenously defined. There are no surprises or disruptions and the model cannot react or respond anyway.

There is a lot of confusion about these types of models. They are not clairvoyant; they cannot predict the future. They cannot predict technical innovations or large structural changes. If they could, modelers would be quite wealthy. There is no “best model” or “correct scenario.”

I have been asked, “how likely is this outcome?” The answer is zero. The models show us tendencies and tradeoffs between different scenarios.

There are many limitations to these models.

Many of the questions we would like to know about the future are exogenously defined (as in, the model cannot calculate future prices and transformative technological innovations). If it could, we would be very wealthy as researchers! Finally, population and economy are exogenously defined (the models are linear), and yet we know that investment in modernizing energy systems (e.g. electrification in developing regions of the world) stimulates growth in new economic sectors.

The solution to climate change is not just a matter of optimizing our current energy system. It is about transforming it. Using the model to tell which horse will win doesn’t really help us. Instead we want to change the rules of the game.

Physical systems vs. human systems (i.e., policy analysis)

We have two philosophical assumptions:

1. Non-Nihilism

   Some outcomes are better than others

   There is a criteria for deciding between them

   If not, policy again would have no purpose because every option would be equally desirable.

2. Non Determinism

   Policy has the power to change things

   We can plan and react

This brings me to an important point about policy analysis- indulge me while I get a little philosophical. Ultimately we are interested in policy analysis, and this requires some philosophical assumptions- that are different from the physical sciences. The first is that we have to assume that some outcomes are better than others, and second we have to assume that we have the power to change things. Models cannot do this- they are non-normative and deterministic.

Key players in the 2050 energy system

1. Energy Efficiency
2. Biomass and Bioenergy CCS (BECCS)
3. Low Carbon Transportation

That said, I want to focus now on three themes: energy efficiency, biomass and bioenergy, and low carbon transportation. Incidentally, these are related to the 3 largest sources of anthropogenic emissions (buildings, agriculture, and transport).

Energy Efficiency

I start with energy efficiency

UNITED NATIONS DECADE OF
SUSTAINABLE ENERGY FOR ALL
2014-2024

UN SE4ALL

The objectives of the SE4ALL are, by 2030, to

1. Ensure universal access to modern energy services
2. Double the rate of improvement in energy efficiency from -1.3% to -2.6% annually (primary energy intensity of GDP)
3. Double the share of renewable energy in the global energy mix from 18% to 36%

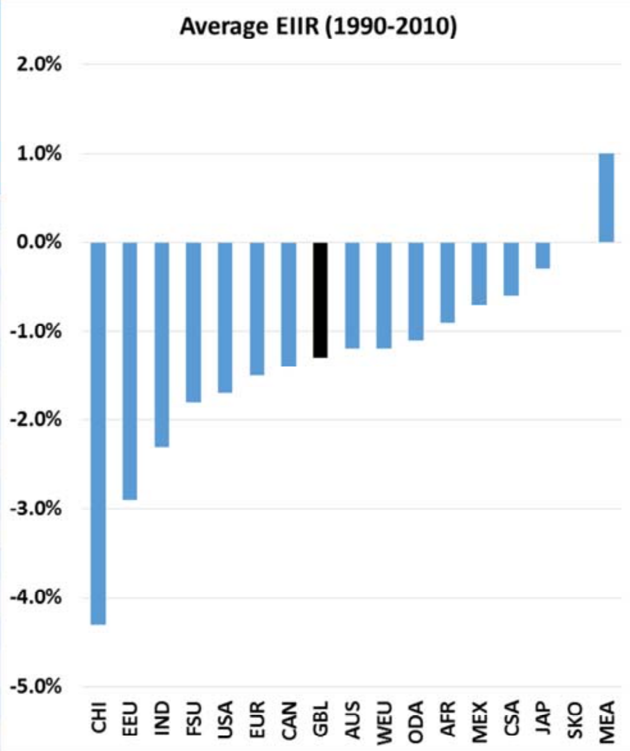
A few years ago, I was involved with using integrated assessment modeling to determine pathways to reach the UN Sustainability For All initiative. This initiative has the goals of ensuring universal access to modern energy, doubling energy efficiency, and doubling renewable energy. I'm going to talk about the energy efficiency goal.

Energy Intensity Improvement Rate (EIIR)

Energy Intensity = Primary Energy Consumption / GDP

“Average” = Compound Annual Growth Rate

Region	Average Annual EIIR, 1990-2010 (%)
AFR - Africa	-0.9
AUS - Australia & NZ	-1.3
CAN - Canada	-1.4
CHI - China	-4.3
CSA - Central and South America	-0.6
EEU - Eastern Europe	-3.0
FSU - Former Soviet Union	-1.9
IND - India	-2.4
JPN - Japan	-0.3
MEA - Middle East	1.0
MEX - Mexico	-0.7
ODA - Other Developing Asia	-1.1
SKO - South Korea	-0.1
USA - United States	-1.7
WEU - Western Europe	-1.2
Global	-1.3



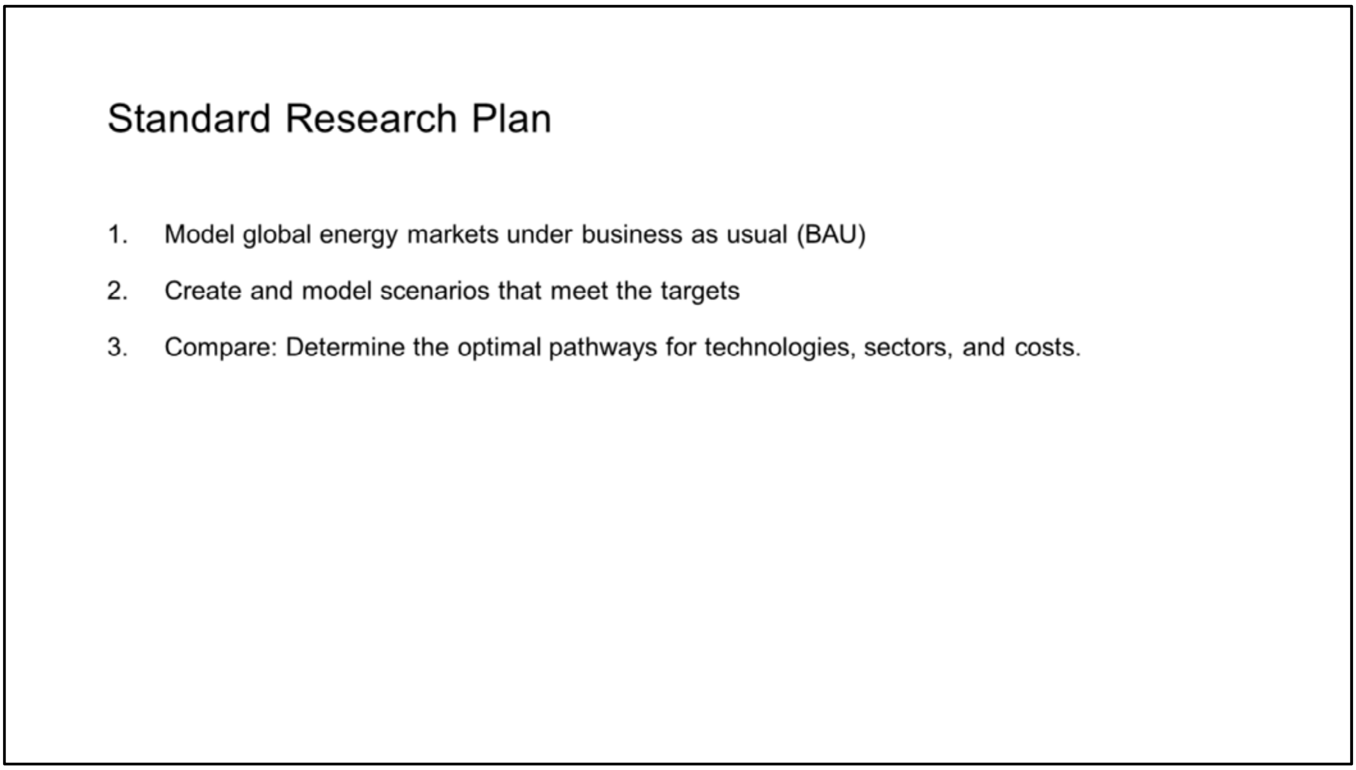
Looking at energy efficiency- most regions of the world have increased GDP at a rate faster than which they have increased energy consumption, leading to a global 1.3% annual reduction in energy intensity (so called EIIR, energy intensity improvement rate). To double this, we can calculate (with the model) the optimal way to reach 2.6% globally. We see it is rather ambitious target, requiring EIIRs much more drastic than we have historically seen.

Energy Intensity Improvement Rate (EIIR)

Energy Intensity = Primary Energy Consumption / GDP
“Average” = Compound Annual Growth Rate

Region	Average Annual EIIR, 1990-2010 (%)	Historic Max EIIR, 1990-2010 (5-year rolling average) (%)	Average Annual EIIR to achieve SE4ALL EE objective (%)	Greater reduction than (1990-2010) historic average?	Greater than historic max reduction (5-year rolling average)?
AFR - Africa	-0.9	-2.3	-2.4	YES	YES
AUS - Australia & NZ	-1.3	-2.5	-3.4	YES	YES
CAN - Canada	-1.4	-3.0	-2.2	YES	NO
CHI - China	-4.3	-6.5	-3.5	NO	NO
CSA - Central and South America	-0.6	-1.4	-1.7	YES	YES
EEU - Eastern Europe	-3.0	-4.8	-3.8	YES	NO
FSU - Former Soviet Union	-1.9	-5.5	-2.2	YES	NO
IND - India	-2.4	-3.4	-2.9	YES	NO
JPN - Japan	-0.3	-1.8	-1.8	YES	equal
MEA - Middle East	1.0	-0.9	-1.8	YES	YES
MEX - Mexico	-0.7	-2.4	-2.6	YES	YES
ODA - Other Developing Asia	-1.1	-2.3	-3.2	YES	YES
SKO - South Korea	-0.1	-2.4	-1.1	YES	NO
USA - United States	-1.7	-2.4	-2.9	YES	YES
WEU - Western Europe	-1.2	-2.0	-2.0	YES	equal
Global	-1.3	-2.0	-2.6	YES	YES

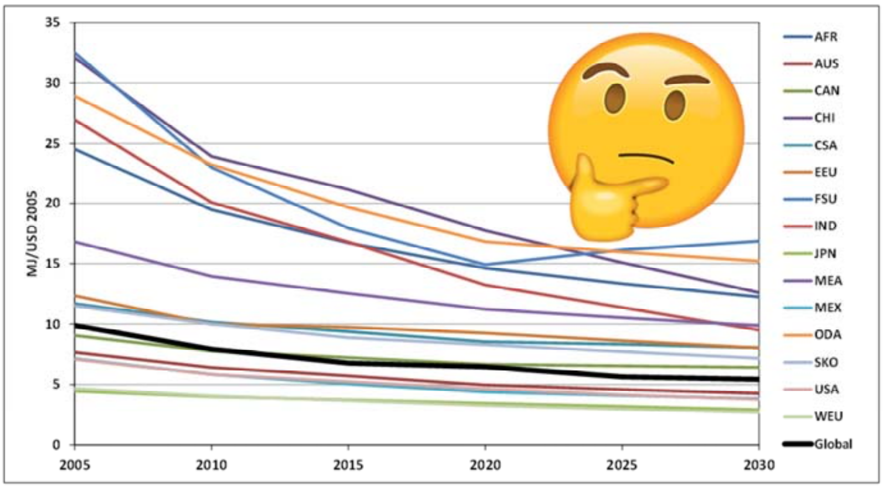
Looking at energy efficiency- most regions of the world have increased GDP at a rate faster than which they have increased energy consumption, leading to a global 1.3% annual reduction in energy intensity (so called EIIR, energy intensity improvement rate). To double this, we can calculate (with the model) the optimal way to reach 2.6% globally. We see it is rather ambitious target, requiring EIIRs much more drastic than we have historically seen.



This is a straightforward research plan for modeling studies- we model a BAU scenario, then we model a scenario that reaches the targets, and we see what the implications are in terms of technology, sectors, and costs

Business as Usual

Regional Energy Intensity Pathways



The modeled (ETSAP-TIAM) economic optimal solution surpasses the SE4ALL target (Global EIIR ~ 3.4%)!

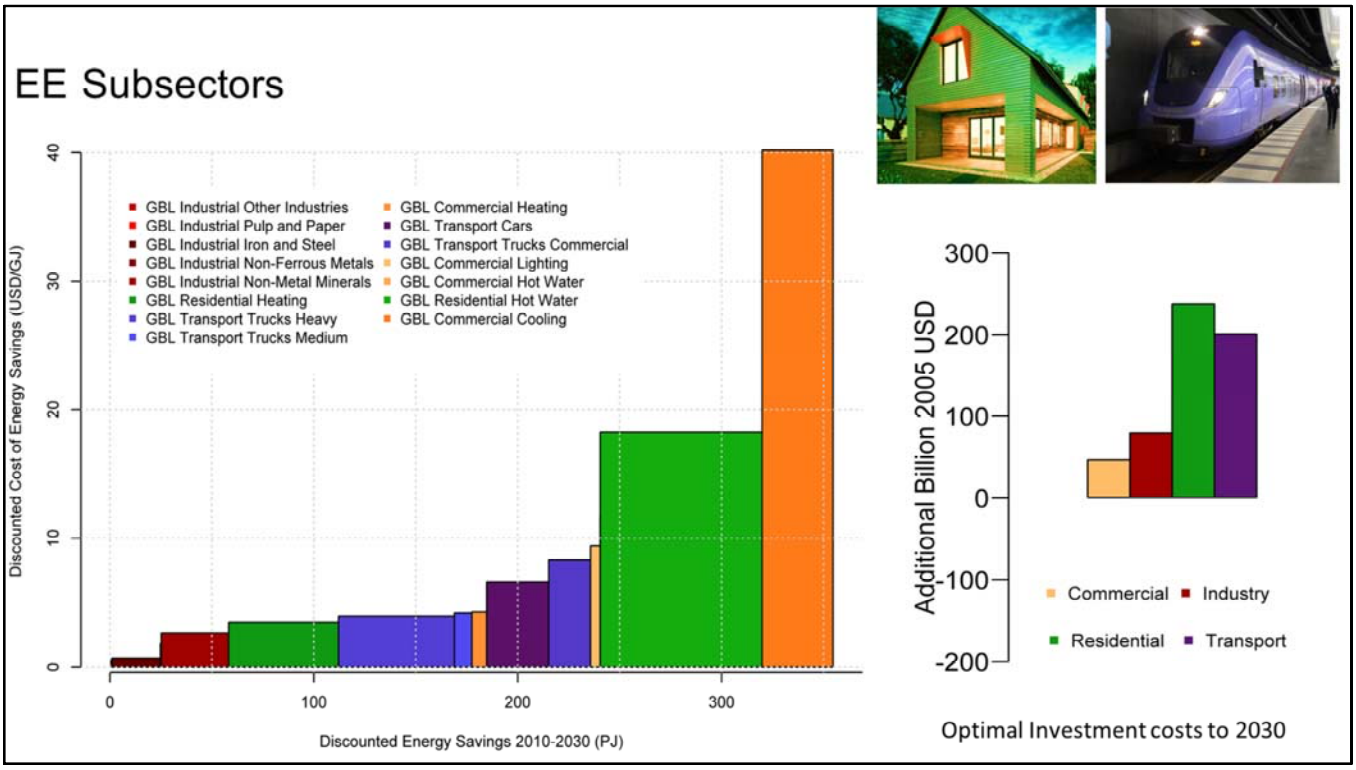
But when we modeled the BAU, we found that the model was already meeting the targets! So the free market has got this one, we can sit back and relax? No. But it does tell us something- that energy efficiency improvements do make economic sense- they are a win-win.

PESTLEG Barriers to EE

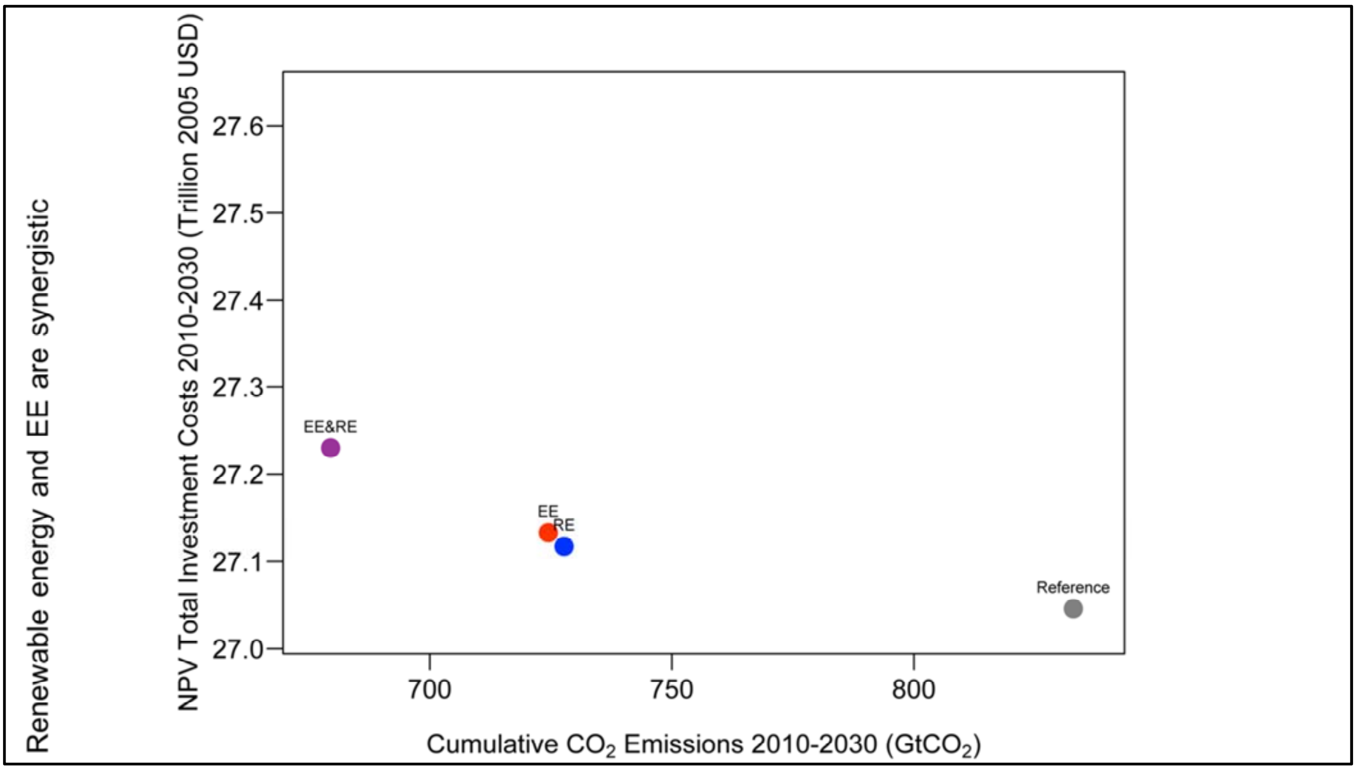
Barrier	Examples
Political	Financial priority
	Value priority
	Political risk
Economic	High initial cost
	Funding possibilities
	Rate of return
	Payback period
	Incentive for owner(s)/user(s)
	Uncertainty
	Transparency of funding possibilities
Social	Actors involved in decision
	Knowledge
	Resources
	Risk averse behavior
	Opposition/resistance

Barrier	Examples
Technological	Infrastructure lock-in
	Enabling infrastructure
	Technologies involved
	Implementation quality
Legal	Data access
	Permitting procedure
Environmental	Environmental side-effects
Governance	Procurement process clarity
	Monitoring of quality

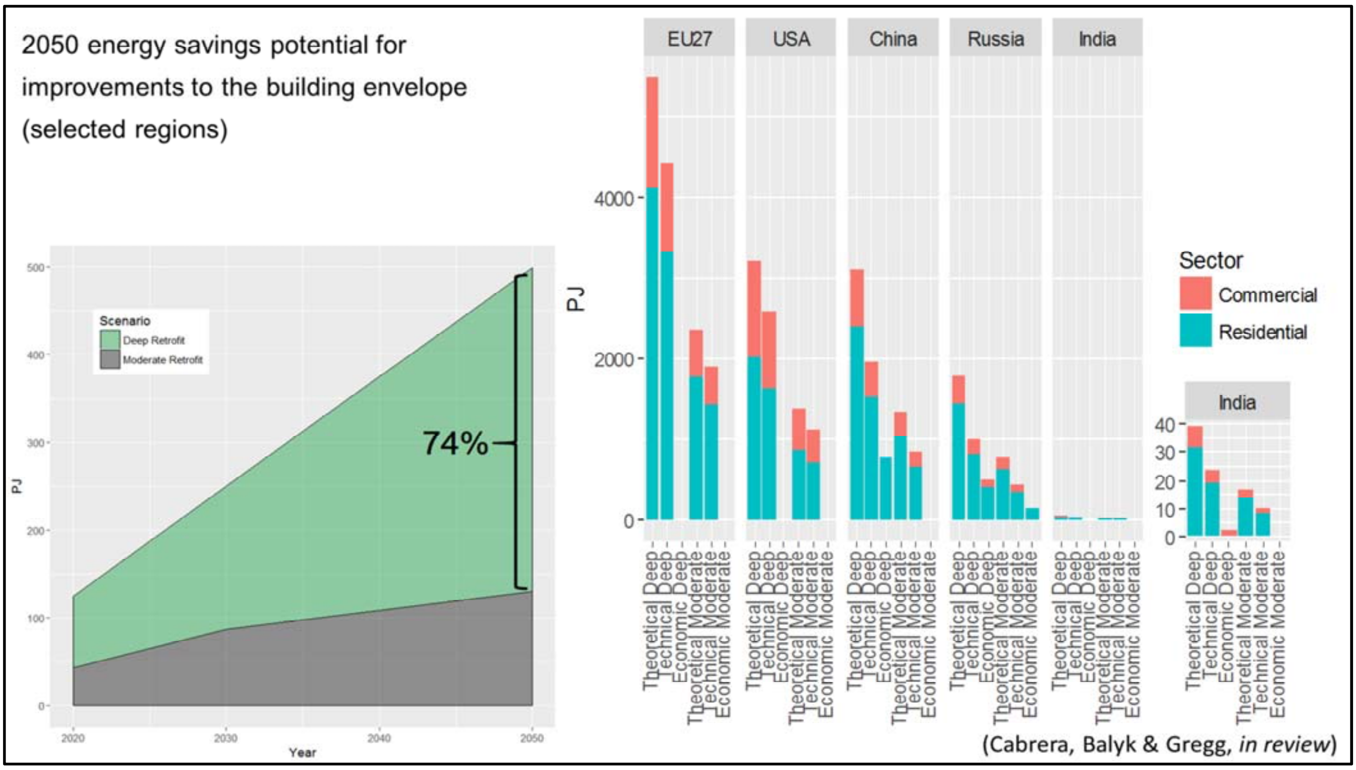
However, there are many non-technical barriers (PESTLEG; or whichever acronym you prefer) to energy efficiency that have to be understood and addressed, and this makes it more than just a technical problem. So we had to create a BAU that was constrained- continuing the historic EIIR



Nevertheless, we persisted and find that the lowest hanging fruit are in the industrial sectors. (In this figure, the industrial subsectors are red hues, transport is blue, residential is green, and commercial is gold). However, the largest potentials and investments needed to reach the target are in the residential and transport sectors.



Another key finding is that Renewable energy deployment is economically synergistic with investments in energy efficiency; that pursuing one policy inspires investment in the other, and that together they reduce emissions more than the sum of the independent polices.



Roughly 75% of the 2050 building stock already exists today- this means renovation will be a key strategy, and high efficient building materials and design will be a key technology moving forward. We therefore expanded the model to consider this. Here there is a large potential for energy savings in retrofitting buildings, particularly in Europe, though we found that the costs of renovation were lower in developing regions. One important consideration with renovation is lock in. We assume that it is unlikely that building owners will undergo successive renovations, therefore, some incentives must be in place so that they choose deep renovations rather then moderate renovation- otherwise, we risk losing almost 75% of the potential savings. Furthermore, strict codes will be necessary for new construction as the world becomes more urbanized (up to 2/3rds of the worlds population is projected to be urbanized by 2050)

Biomass and Bioenergy

I want to move to the second topic, biomass, which remains one of the “wild cards” and one of the resources with the largest uncertainties going forward in the future. Bioenergy is our largest source of renewable energy (13% of global final energy demand).

Bioenergy & BECCS

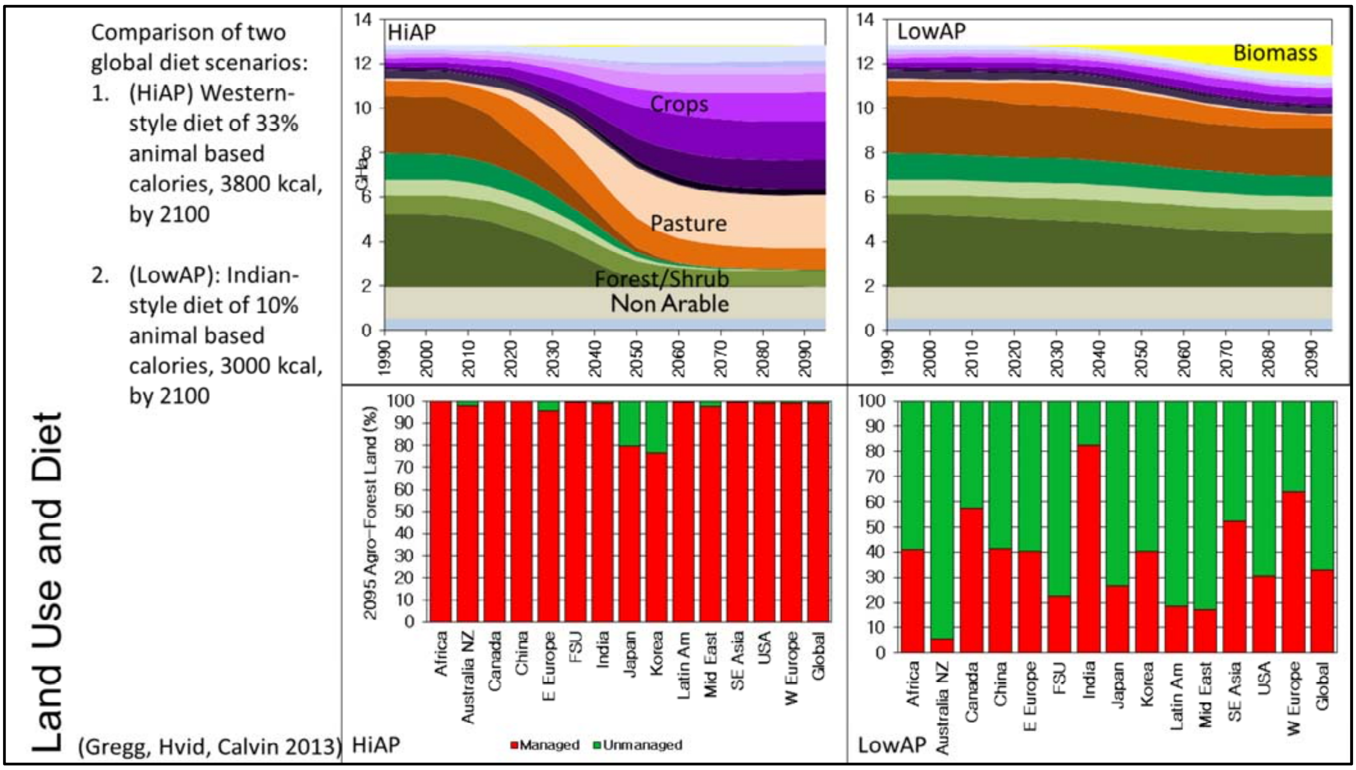
Bioenergy:

- Biofuels will be needed for shipping, heavy transport and air travel
- Biomass is also essential for decarbonizing the chemical industry

BioEnergy Carbon Capture & Storage (BECCS):

- Will likely be necessary to reach a zero carbon energy system (to offset some positive carbon fuel sources)
- The only "reverse gear" for decarbonization pathways; most scenarios now show that emissions reductions alone are not enough to reach our target.
- Without BECCS, even more biomass is needed for the renewable energy portfolio

The future energy system will need biofuels and bioenergy. Biofuels will still be needed for some applications, such as heavy transport and air travel. Biomass is also an important chemical feedstock.
BECCS is an interesting case. About 15 years ago, it was seen as a theoretical risk management option. Now, regrettably, it is appearing to more of a necessity.



However… to the degree this is possible depends on the potential supply of biomass. Here, I model two diet scenarios: the first the world evolves to a an average western diet (US, Canada, Europe, Australia) with 33% animal products with 3800 kcal/person/day, and the other is an Indian style diet with about 10% animal products and 3000 kcal/person/day.

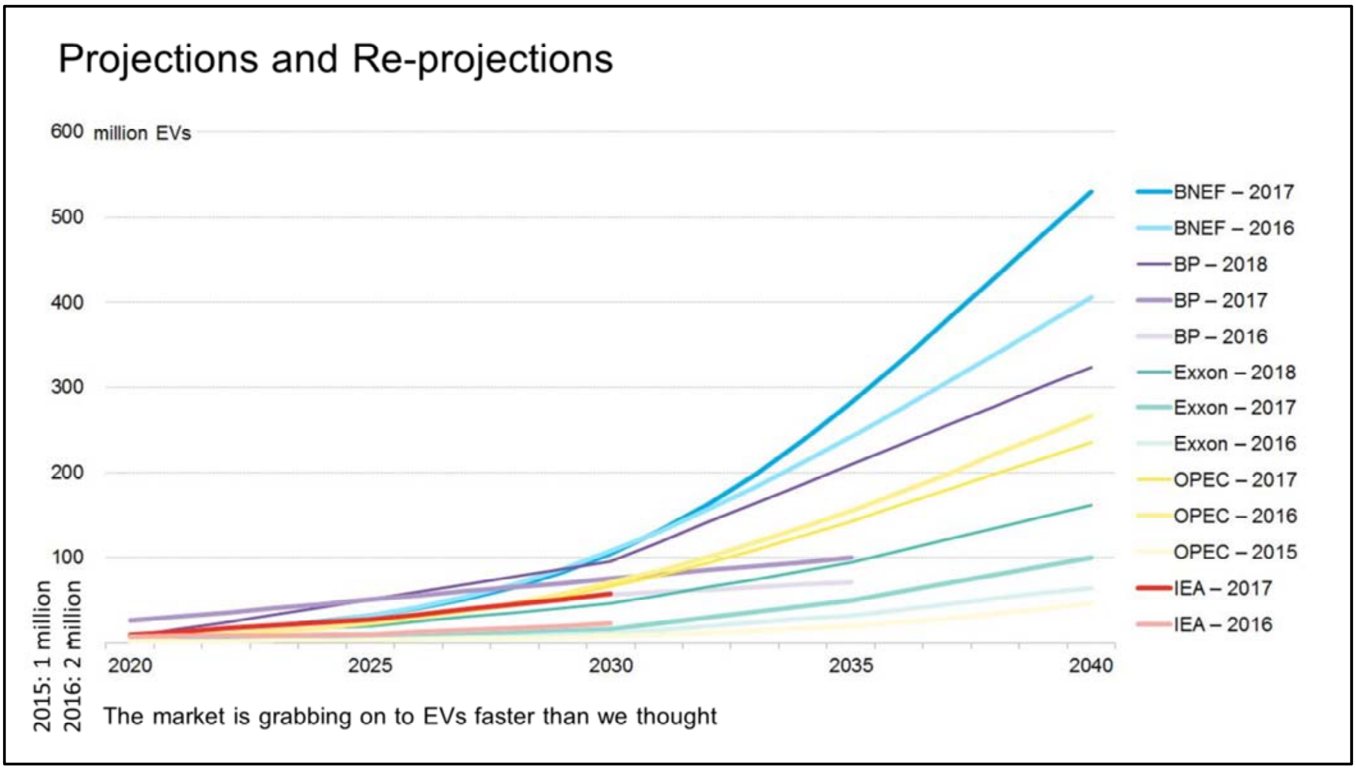
Food is part of the energy system

- Food is energy! Fertilizers, transport, biomass, etc.
- From a systems perspective, we cannot talk about the energy system without considering the future of food.
- We need to find some way to limit bioenergy!
  - Food
  - Nature
  - Well being

We tend to compartmentalize a bit here, there is the energy system, and then there is food production. But they are inextricably linked. We don’t talk about diet when we talk about energy, but we need to begin to have that conversation. Food is energy, after all.

Transportation

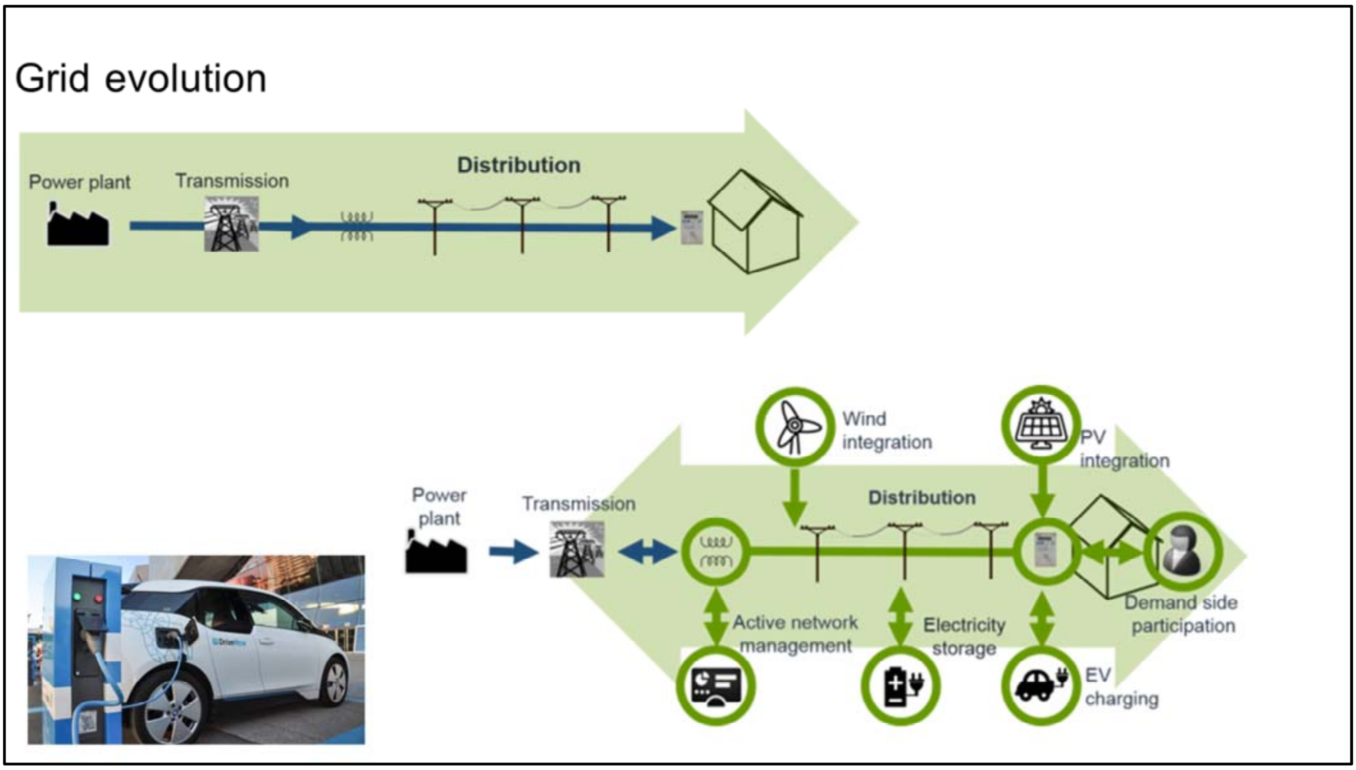
The third theme I want to talk about is transportation. We are at the beginning of a revolution in transportation- how we power it, how we think about it, and its level of integration with the energy system.



In 2015, there were 1 million EVs, in 2016, there were 2 million. The projections for market uptake are being radically adjusted upward every year.

We must electrify the vehicle fleet (and/or move to hydrogen) if we want to reach a zero carbon energy system (90% of European vehicles are powered by fossil fuels).

We are at a point where there would not be much extra that could do through public action – except for banning diesel and gasoline car sales from a certain point in time (2035 at latest).



This also, along with smart technology and prosumers, will radically transform our grid. Prosumers could produce up to 45% of Europe's electricity by 2050 (CE Delft Study / REScoop)

Game Changers: Autonomous Vehicles

SAE Level	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fall-back performance of dynamic driving task	System capability (driving mode)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n.a.
1	Driver Assisted	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* performs all remaining aspects of the *dynamic driving task*	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	All driving modes

Forecasts:

2018-2020: Nutonomy (taxis)

2018: Tesla

2018: NVIDIA (Level 4)

2019: Delphi & MobilEye

2019: VW

2019: Baidu

2020: GM

2020: Nissan (Level 4)

2020: Toyota (Level 4)

2020: Audi (Level 4)

2021: Ford (Level 5)

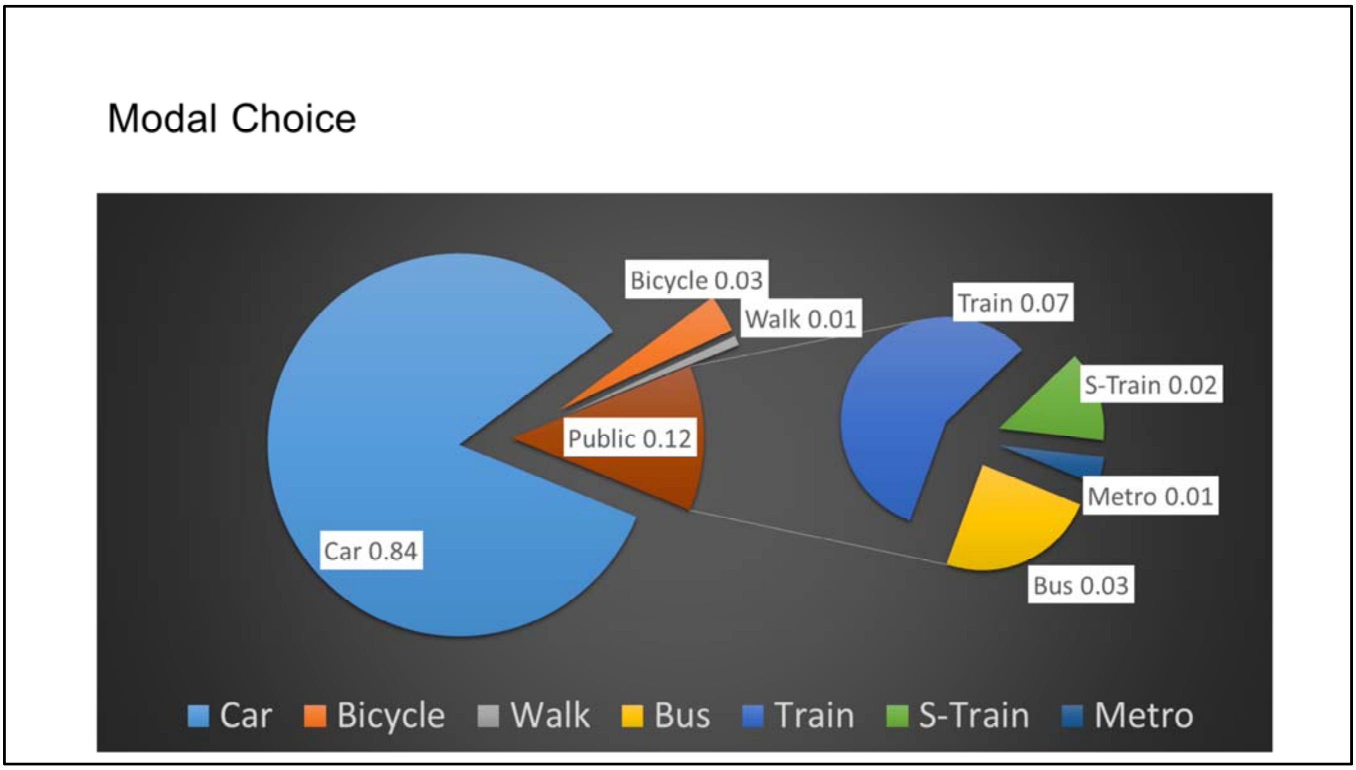
2021: BMW

2023: Tesla (Level 5)

2040: IEEE 75% will be A.V.

http://www.driverless-future.com/?page_id=384

This will change the way we think about transportation. The evolution of autonomous vehicles is a huge potential game changer. What is most interesting is the level 5 automation, where the auto has no user controls. This likely will change ownership models to MaaS. It also has the potential to shift demographics of our cities. Industry predictions show that the will be the transition period is in the coming years, not decades.



Even in Denmark, which has tax rates of around 100% on the purchase of vehicles, and no auto industry, the majority of trips are still done by private car. The analysis of the trend of modal split of the alternative scenarios points out that introducing effective taxation schemes, parking pricing and toll collection; decreasing the public transit ticket price, park and ride facilities and charging infrastructure for electric bikes; increasing the frequency and expansion of public transit infrastructure encourage travelers to shift away from car use; but not much. Ultimately, we need more of a pull from an alternative form.

Conclusions

Finally some conclusions

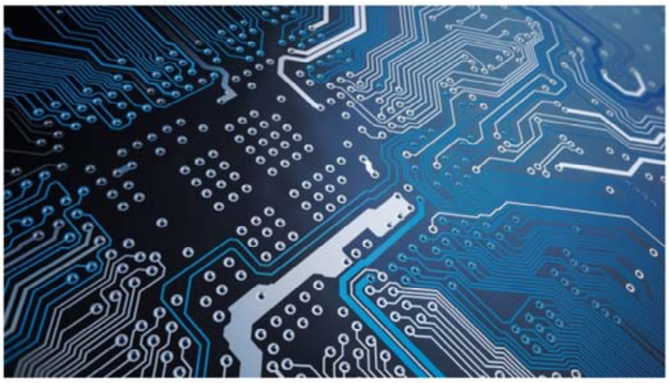
What does the energy system look like in 2050?

- Urbanized, more distributed generation, smart systems, energy efficient buildings, battery storage
- MaaS, autonomous vehicles
- High integration of electrical grids allowing for high levels of intermittent renewables
- Central power plants with BECCS
- Sharing economy, circular economy

What does the energy system look like in 2050? We don’t know. There will likely not be a “winning horse” and not only that, we are changing the game entirely. We need to. Here are some trends that and developments we will likely see.

Key technologies

- High efficiency building materials suited for retrofit
- High efficiency technologies for heating, cooling, and hot water heating, heat storage and transfer
- Battery technology
- Plant-based animal product substitutes
- BECCS
- Bio-enzymes
- Autonomous Vehicles



Likewise, these are some of the key technologies moving forward, and these will likely be necessary to reach a zero carbon energy system. Many of them also are potentially double edged swords.

Key Social and Economic Factors

- Ownership and incentive models for building investments and retrofit
- Urban design
- Prosumer networks
- Diet
- Transportation mode incentives
- Circular and sharing economies

And I want to re-emphasize that this is not solely a technical problem. There are important social factors transitions that must also be present.

What does this mean for R&I at the EU?

Technology is essential, though technology alone cannot solve the climate issue.

We are seeing a greater degree of integration:

across sectors within the energy system

across systems themselves

(energy, food, water, climate, social systems, values)

From compartmentalization to systems thinking

From ambitious to aggressive policies

Going to a zero C energy system is a socio-technical transition

Essentially, to reach a zero carbon energy system by 2050, we are getting to the point where we need a revolution, not an evolution. That should make us nervous, because revolutions can be painful. On the other hand, done well, they can really benefit us all.

Thank you!